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GENERAL GUIDELINES FOR DEFICIT IRRIGATION MANAGEMENT[1/]

Jack T. Musick
Agricultural Engineer (Collaborator)
USDA Conservation and Production Research Laboratory
Agricultural Research Service
Bushland, TX 79012

INTRODUCTION

Deficit irrigation involves reducing water application below the requirement for maximum yield and thus involves significant risk for yield reduction. As primarily practiced in the Great Plains, deficit irrigation involves using a limited water supply over a larger area than can be irrigated adequately for high yield which permits reducing the area in dryland crops and fallow. Under good management, deficit irrigation can significantly increase yield response per acre-inch of water applied and total farm production with limited available water supplies. Deficit irrigation was discussed by English et al., 1990; Martin et al., 1992; Musick and Porter, 1990; and Musick and Stewart, 1992.

Since deficit irrigation normally involves slight to moderate yield reduction and thus increases per-acre production risks, it needs to be considered carefully before being practiced. Some general guidelines for deficit irrigation management are discussed.

First, I will point out that expected precipitation is important relative to the practice of deficit irrigation. It is not normally practiced in humid climates where precipitation is the primary water supply for crop water requirements and irrigation is of limited importance for high yields. Also, it is not generally practiced in arid climates where crop production is almost entirely dependent on applied irrigation. It is primarily practiced in semiarid regions where rainfall furnishes a substantial part of crop water requirements but irrigation is essential for attaining high yields in most seasons.

The High Plains experiences relatively high climatic variability with growing seasons ranging from wet to dry. In the wet seasons, very little irrigation is required while in the dry seasons, irrigation is required to furnish

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The discussion is presented under three important aspects of SOILS, CROPS, and MANAGEMENT and is based on the assumption that farm water supplies available for irrigation are limited in relation to land area. Management practices to reduce water application were discussed by Musick and Walker, 1987.

SOILS

A general guideline is to only consider deficit irrigation of soils that have a relatively deep profile for root growth and water extraction (3 to 8 ft) and that have moderate to high plant-available water storage capacity (5 to 12 inches). These soils mostly have profile textures ranging from silt to clay and plant-available water storage capacities of 12 to 17% by volume. Examples of irrigated soils having high water storage capacities are the deep silt loams of western Kansas (Keith, Richfield, and Ulysses series).

In deficit irrigation management, it is important that soil profiles be relatively wet to near storage capacity at the beginning of the season or that wetting be provided by irrigation prior to the rapid vegetative growth period. A wet profile allows water deficits to develop gradually as plant roots grow into moist subsoil. Slow development of plant water deficits allows some plant adjustment to the drier conditions (primarily by osmotic adjustment of the water status of plant cells). This limits yield reduction and provides some time flexibility for scheduling the next irrigation.

Soils with shallow rooting depth or course-textured profiles (deep sands) with low available water storage capacities probably should not be deficit irrigated. These soils allow more rapid development of plant water stress to severe levels and increase the risk of excessive yield reduction.

Some soils with sandy surface textures have moderate to fine-textured subsoils and moderately high water storage capacities. These soils can be managed successfully with deficit irrigation. An example is the sandy loams (Amarillo series) in the Southern High Plains that have silty clay subsoils that are managed successfully for deficit irrigation of cotton.

CROPS

A general guideline for deficit irrigation in the High Plains is to limit the crops to those that possess drought resistance and can be grown successfully with dryland management. Drought resistance has been defined as *tolerance and/or avoidance*. Crops that possess drought avoidance have either a short growing season or develop a deep root system for water extraction or both. A good example of drought avoidance is sunflower which has both a deep root system and a short growing season.

Some of the crops that can be managed by deficit irrigation, if irrigated, are winter wheat, grain and forage sorghum, cotton, barley, millet, alfalfa for seed, sunflower, sugarbeets, grapevines, and cool season grasses

(grasses managed without summer irrigation when growth is slowed by hot temperatures).

The major dryland crops, winter wheat and grain sorghum, are the most widely grown under deficit irrigation in the High Plains. Research has shown that stage of plant development is an important consideration for best management for deficit irrigation when water is applied by surface methods. In general, highest grain yield response has been obtained for irrigation applied during a 3 to 4-week period approaching and continuing through pollination and seed set. These development stages primarily determine seed numbers per unit ground area which is a more critical grain yield component than seed weight. Also, soil water storage by irrigation at this time is fully utilized as seasonal water use. Irrigation during grain filling can leave some unused water stored in the soil profile after maturity.

By beginning the growing season with a relatively wet soil profile, a successful strategy for deficit irrigation of drought tolerant crops can be to reduce application by delaying or deleting an early season irrigation. This is a period of rapid root growth extension into moist subsoil which slows the development and limits the severity of plant water stress.

A second successful strategy is to delete a late season application by advancing irrigation cutoff date which increases crop use of available soil water storage. Also, increasing soil water depletion before crop maturity increases precipitation storage efficiency between harvest and planting the next crop (Musick, 1970).

Two crops are discussed as illustrative examples of whether deficit irrigation should or should not be practiced when water supplies are limited. Winter wheat is discussed as a water-stress tolerant crop that can be managed successfully with deficit irrigation. Corn is discussed as a water-stress sensitive crop that probably should not be deficit irrigated of deficit irrigation should be practiced with caution.

Winter Wheat

Deficit irrigation of winter wheat was discussed by Musick and Porter, 1990; Dusek and Musick, 1992; and Musick et al., 1994. Winter wheat yield response data were summarized for seven field tests conducted at Bushland during 1988-94 on Pullman clay loam. Each test included eight or nine treatments with spring water application as none, one, two, three, and in five of the seven tests, four applications for maximum yield. Irrigations (mostly 4-inch) were applied by gated pipe to level border plots that were diked to prevent runoff. Applications were made at one or more development stages of early jointing, boot, flowering, and about mid-grain filling. Nitrogen and phosphorus fertilizer was applied for high yield.

One or two semidwarf varieties (TAM 105, TAM 107, TAM 200, TAM 202) were evaluated in each test. Wheat was planted in late September or early October following summer fallow on a plot area that had a wet soil profile at planting. The soil has a plant-available water storage capacity for winter wheat of 10.2 inches to 6.6 ft, the measured rooting and water extraction depth.

For the treatment adequately irrigated for high yield, seasonal water use averaged 28.6 inches, water application averaged 15.2 inches, and seasonal precipitation averaged 8.6 inches. Average grain yields ranged from 45.7 bu/acre with no spring irrigation to 95.9 bu/acre with adequate irrigation. The best yield response to one spring irrigation varied between jointing and flowering, depending on the season, and averaged 5.6 bu/acre-inch; two irrigations averaged 4.3 bu/acre-inch; three irrigations averaged 3.9 bu/acre-inch; and adequate irrigation for maximum yield averaged 3.4 bu/acre-inch. The adequate irrigation treatment included a 3.2 to 4.0-inch irrigation about mid-grain filling. The yield response to this irrigation averaged only 1.7 bu/acre-inch. The yield response was low because of late season rainfall following irrigation and only partial use of the soil water stored by the grain filling irrigation.

The results with winter wheat indicate that stage of plant development is important for obtaining most efficient yield response to water applied as deficit irrigation. A 3 to 4-week period approaching and continuing through pollination was the most critical for water deficits and the most responsive to applied irrigation. Yield response to irrigation applied during grain filling was substantially lower. Also, some tests have shown low yield response to applied irrigation during late fall or after beginning spring growth when soil water depletion and additional storage capacity were limited at the time of irrigation.

Corn

Results from irrigation tests with corn in the Central and Southern High Plains in general indicate that deficit irrigation should not be practiced (Lamm et al., 1993 and 1994; Musick and Dusek, 1980). However, deficit irrigation is more likely to be successful in areas where corn can be grown successfully as a dryland crop. As a stress-sensitive crop, the reduction in water application below the requirement for maximum yield should be limited.

When applied in graded furrows, probably the most successful deficit irrigation management practice for corn is to use an early termination date by not applying a late season irrigation past mid-grain filling (grain dent stage). The yield effects from eliminating a late grain filling and successive earlier seasonal irrigations in an irrigation-plant density study conducted on Pullman clay loam during 1992-94 are presented in Figure 1. The limited yield reduction from deleting the late grain filling irrigation, compared with deleting any other seasonal irrigation, was associated with increased allowable depletion of available soil water during the latter phase of grain filling when yields are less sensitive to plant water stress effects.

A survey of 82 irrigated corn fields for soil water contents after harvest in Thomas and Sherman counties, northwest Kansas, indicated mostly relatively high soil water contents after harvest that were common for both sprinkler and furrow irrigated fields (Rogers and Lamm, 1994). Available soil water contents after harvest averaged 70% of field capacity for silt loam soils that had about 10 inches of available storage capacity to 5 ft.

It seems logical that if water application is reduced for corn, plant densities should be reduced also. For the data presented in Figure 1, plant densities were evaluated for management of adequate and deficit irrigation. Plant densities in the range of 24,000 to 28,000/acre were adequate for maximum yield of a full season hybrid (Pioneer 3162). As yields were reduced by deficit irrigation, yield response became less sensitive to plant densities and optimum densities were in the range of 20,000 to 24,000/acre.

The elongation growth of corn silks, essential for emergence from the ear to permit pollination, is much more water-stress sensitive than pollen shedding. A critical development stage for corn is when plant water stress delays silk emergence past pollen shedding. High plant densities accelerate the beginning of plant water stress, increase stress severity, and should be avoided when irrigation supplies are marginal or deficit irrigation is practiced. For the data presented in Figure 1, rainfall prevented plant water stress in deficit irrigation treatments during pollination in all three seasons.

Water Application — Grain Yield Relationship

The yield response over a range of applied irrigation can be linear or curvilinear (diminishing yield return with increased water application). When the yield response is linear, adequate irrigation for high yield is the most economic water allocation (Lamm et al., 1993). An exception may be if the water has greater value when used to irrigate an alternative crop. When the yield response to increasing water application is a curvilinear diminishing return function, yield optimization occurs at a reduced level of water application than required for maximum yield.

Yield response for a range of water application for corn production at Colby, Kansas, are presented in Figure 2 to illustrate linear response functions (Lamm et al., 1993) and in Figure 3 to illustrate curvilinear functions (Lamm et al., 1994). In these tests, water was surface applied to level border plots with dikes to prevent runoff.

For the 1986-88 test results presented in Figure 2, water application ranged from 3 to 6 inches for the driest treatment in each test to 12 to 18 inches for the wettest treatment, which yielded about 160 bu/acre. The tests were designed to limit water application to 3 inches in a 10-day period for the wettest treatment. For these test conditions that placed an upper limit on water application and grain yield, the yield response to applied irrigation was linear.

For the 1990-91 test results when water application was increased to 20 to 22 inches, yields were increased to 210 to 220 bu/acre and the yield response function was curvilinear diminishing return, Figure 3. The curvilinear yield response obtained in the high water application-yield range indicates potential for reducing application by about 20% with only minor yield effects. A general guideline is to consider deficit irrigation to reduce water application in the high water-yield range where the yield response is likely to be curvilinear but exercise caution in further reducing a moderate level of application where the water application-yield response function is likely to be linear.

MANAGEMENT

In the High Plains, many irrigation systems are located in areas that have experienced substantial groundwater decline and reduced pumping rates. Adjustment trends to groundwater decline and increased pumping energy costs (since the mid-1970s) have been to both reduce per-acre water application for most crops and reduce irrigated crop area (Musick et al., 1990). Management practices and systems that can be considered for reducing water application and improve management of deficit irrigation are discussed.

Irrigation Systems

Sprinkler and furrow irrigation trends were discussed for the Texas High Plains by Musick et al., 1988. Sprinkler replacement of less efficient furrow irrigation has and continues to be a significant development for reducing per-acre water application. New (1986) indicated that center pivot sprinkler irrigation is effective in reducing per-acre application by 20 to 25%. Reducing irrigation depths can increase yield response per acre-inch applied when compared with application depths normally used in surface irrigation (Musick and Dusek, 1971).

Cropping Systems, Tillage, and Cultural Practices

Cropping systems can involve crops that spread the demand for irrigation water such as the wheat-sorghum-fallow or wheat-corn-fallow systems in which the two crops have different irrigation seasons. These systems have 10 to 11 months fallow between each crop that normally results in good profile soil water storage from precipitation. Precipitation storage can be increased by no-tillage management after irrigated wheat using herbicides for weed control. In tests by Musick et al. (1977), soil water storage at planting of grain sorghum following irrigated wheat was increased by 1 to 2 inches using no-tillage management compared with conventional disk tillage. No-tillage that leaves wheat stubble standing not only increases soil water storage by reducing evaporation but also increases storage by increased snow trapping.

When beds and furrows are desired for bed-planting of corn or sorghum, planting without the need for a preplant irrigation can be successful by performing tillage and reforming beds and furrows soon after harvest (Musick et al., 1977). This allows an extended time period between crops for rewetting of beds by precipitation. Shallow cultivation is used to minimize evaporation losses following tillage. An alternative is flat tillage and planting after rainfall wetting of the surface soil seed zone and forming water furrows for row crops during cultivation prior to the first seasonal irrigation. Flat tillage and planting after rain has been successful for planting grain sorghum in late May or early June without the need for preplant irrigation for stand establishment (Allen and Musick, 1990).

Planting date, water management, and maturity length relations for irrigated grain sorghum were discussed by Allen and Musick, 1993. In the Southern High Plains, grain sorghum planting dates range from early May to mid-to-late June. Planting dates influence the selection of hybrids for maturity length with commonly grown hybrids differing in maturity by about two weeks. A full season hybrid planted in mid-to-late May will require one additional graded furrow irrigation compared with a medium maturity hybrid planted early to mid-June. The medium maturity dryland types have good drought tolerance and yield response to reduced water application and should be considered for deficit irrigation. Also, medium maturity hybrids allow more planting date flexibility which enhances successful planting after rain without requiring a preplant irrigation.

Delayed planting of grain sorghum reduces tillering because of increasing temperature which limits potential tiller head contribution to grain yield. Adequate plant densities of 60,000 to 80,000/acre are more important for delayed planting in June than for early planting in May when cooler early season temperatures allow increased tillering. "Super thick" plant densities in excess of 100,000/acre should be avoided because high plant densities accelerate the development of plant water stress.

Preplant Irrigation

Preplant irrigation was reviewed for the Central and Southern High Plains by Musick and Lamm, 1990. The yield response per acre-inch of surface-applied water as preplant irrigation has averaged about one-half of the yield response to seasonal irrigation of grain sorghum. However, the average yield increase from an additional acre-inch of stored soil water at planting averages about the same as the average yield response to an acre-inch of applied seasonal irrigation.

The low yield response to preplant irrigation in surface irrigation systems is associated with 1) excessive graded furrow intake relative to storage capacity in the soil profile, 2) an extended time period after wetting for surface evaporation and profile drainage to occur before the stored soil water is used for plant growth, and 3) greatly reduced rainfall storage following preplant irrigation because of wet soil and lack of additional storage capacity.

Cultural practices for stand establishment without preplant irrigation were pointed out in previous sections. Many management practices that are used successfully for stand establishment of dryland crops can be used successfully for irrigated crops. Water use efficiency of crop yield from preplant irrigation can be increased by intake control to reduce graded furrow application as discussed in the following section.

Water Intake Control in Surface Irrigation

In practicing deficit irrigation management in graded furrow systems, large application depths can be reduced by systems and management that limit water intake. Field tests indicated a 20 to 30% reduction in application depth is attainable by use of surge-flow application (Musick et al., 1987), by wheel traffic compaction of irrigation furrows (Musick et al., 1985; Musick and Pringle, 1986), and by use of wide-spaced furrows or alternate furrow irrigation (Musick and Dusek, 1974).

Wide-spaced bed-furrows can be used to maintain wheel traffic on the wide beds which increases uniformity of furrow intake and water advance. Uniform furrow advance permits reducing tailwater runoff. The most successful wide bed-furrow system tested has been 60-inch spacing of water furrows, compared with irrigating 30-inch spacing, and 30-inch spacing of summer row crops with each crop row having one side adjacent to an irrigated furrow. When wheel traffic is used to reduce furrow water intake during a preplant irrigation, furrow ripping can be used prior to the first seasonal irrigation to largely restore normal furrow intake during seasonal irrigations (Allen and Musick, 1992). Furrow ripping can cause some root damage and irrigation should immediately follow ripping.

Because of the time required for furrow applied water to advance to the end of the field, a lower field section will experience reduced water intake and yield unless substantial tailwater runoff time and amount are allowed. Research tests to reduce or eliminate tailwater runoff for winter wheat and grain sorghum on Pullman clay loam were reported by Allen and Musick, 1994; Schneider et al., 1976; and Stewart et al., 1983. Although this practice increases lower-field soil water deficit, the reduced lower-field water intake can be used efficiently for grain yield (Musick et al., 1973).

The success of reducing or eliminating tailwater runoff by graded furrow irrigation can be enhanced by deeper than normal tillage of a lower field section to increase water intake rates that compensate in part for reducing flow duration (Musick et al., 1981). Diking the end of the field allows temporary storage and time flexibility for all furrows to advance to the end of the field before irrigation cutoff. For furrow irrigated fields, deeper than normal tillage should be restricted to a lower field section, probably about the lower one-fourth of a half-mile field and the lower one-third for a quarter-mile field. Deeper than normal tillage of the entire field can result in excessive application depths and significant losses to deep profile drainage.

SUMMARY

Deficit irrigation involves using a limited water supply over a larger crop area than can be irrigated adequately for high yields. It is widely practiced for irrigation of drought resistant crops in the Central and Southern High Plains. Practices than can be managed successfully for deficit irrigation are discussed as follows: 1) seasonal precipitation as an important contribution to plant water requirements; 2) soils that have relatively high water storage capacities; 3) begin the season with relatively high soil water storage; 4) grow crops that possess drought resistance and can be grown successfully by dryland management; 5) consider crop development stages for best yield response to water applied as deficit irrigation; 6) manage irrigation for major soil water depletion by maturity; 7) use management practices to increase the contribution of precipitation to crop water requirements; 8) use management practices that reduce or eliminate the need for preplant irrigation; 9) increase irrigation application efficiency (reduce or eliminate tailwater runoff or convert from furrow to sprinkler irrigation); and 10) reduce graded-furrow water intake by use of surge-flow application, wheel traffic compaction of furrows, or by irrigation of wide-spaced or alternate furrows. Water stress sensitive crops such as corn probably should not be deficit irrigated or deficit irrigation should be practiced with caution.

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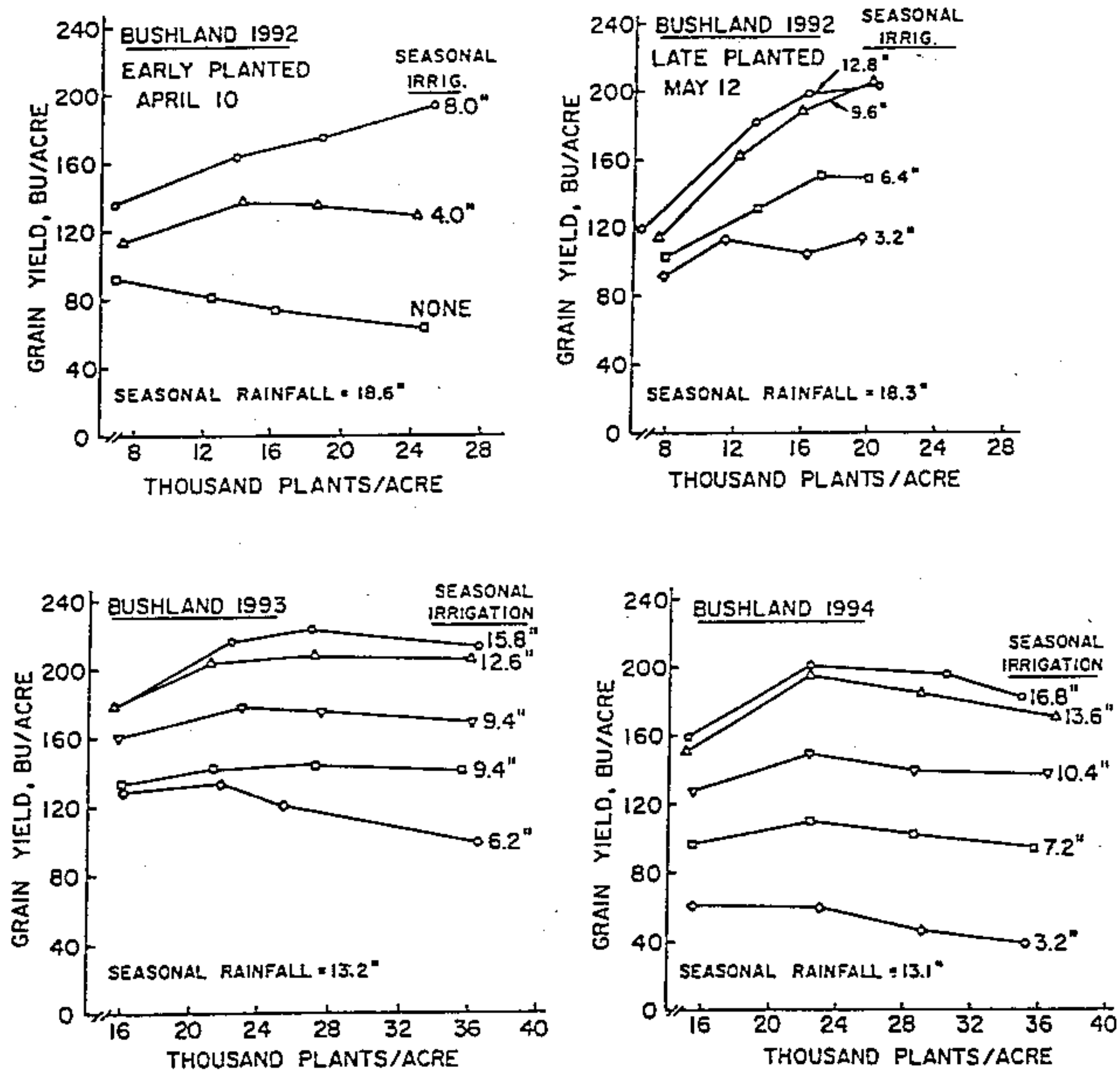

Figure 1. Corn grain yield response to irrigation water level and plant density of a full season hybrid (Pio. 3162), Bushland, Texas, 1992–94. Irrigation levels represent successive applications to level border plots and illustrate the small yield response from deleting a late grain filling irrigation.

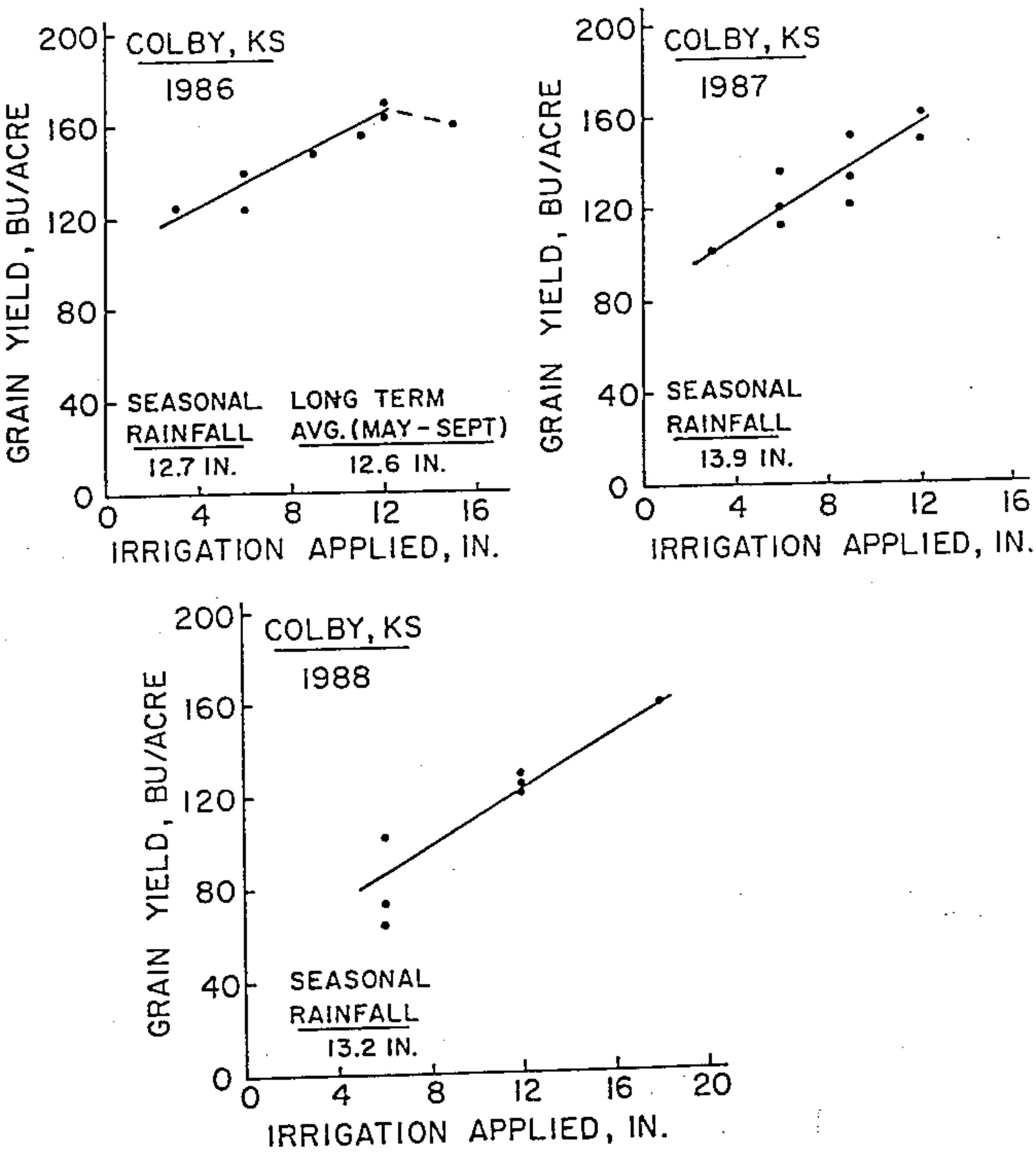

Figure 2. Corn grain yield response to water application to level border plots at Colby, Kansas, 1986–88, that illustrate linear response functions when total water application and yields were limited. Adapted from Lamm et al., 993.

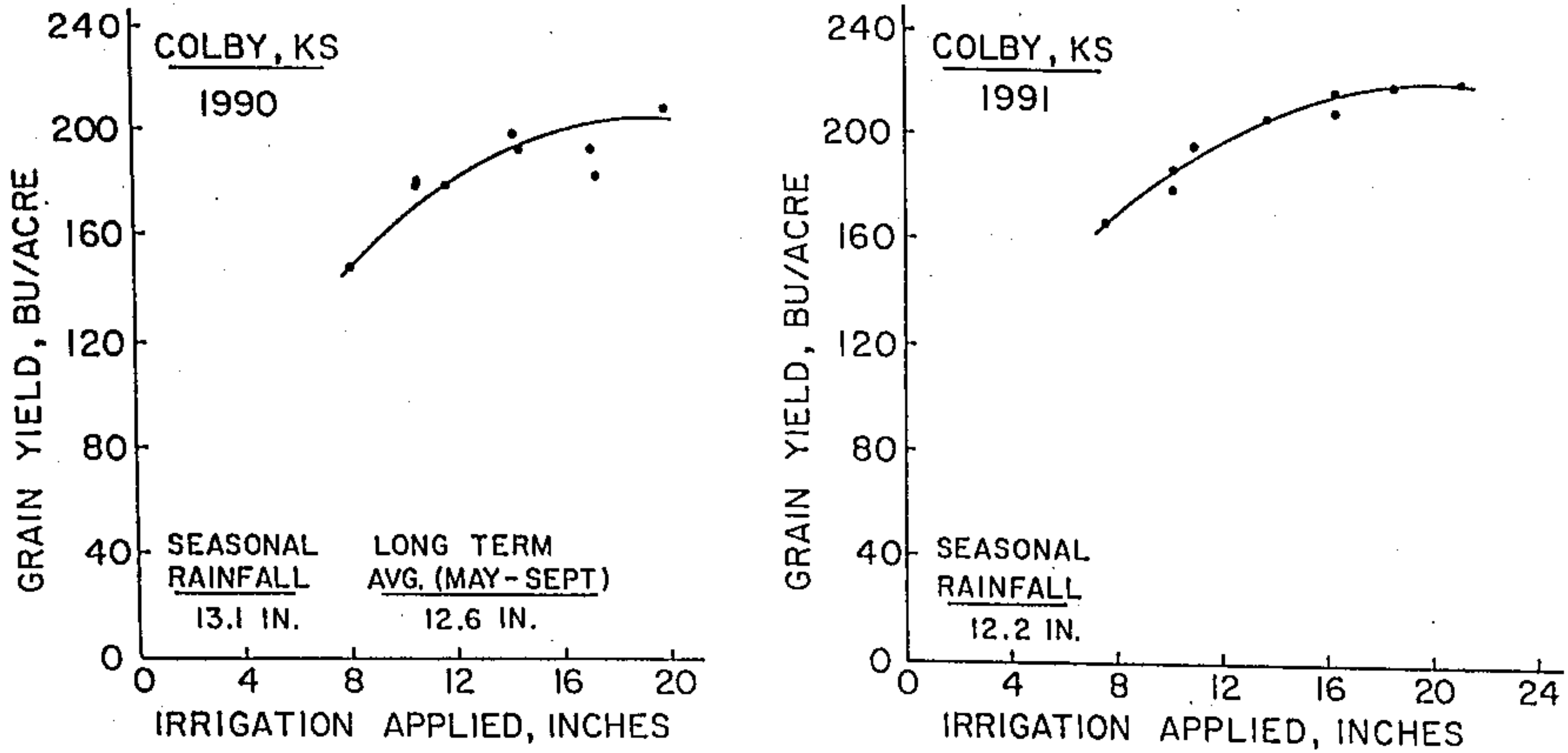

Figure 3. Corn grain yield response to water application to level border plots at Colby, Kansas, 1990–91, that illustrate curvilinear response functions when the response function extends into the high water application-yield range. The curvilinear diminishing return function permits yield optimization by reducing water application for maximum yield. Adapted from Lamm et al., 1994.